HUPMOBILE

A2.3 *Participatory Simulation Model Development for Sustainable Urban Mobility and Logistics*

HUPMOBILE – Holistic Urban and Peri-urban Mobility
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Imprint

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Project note

The EU co-funded project **HUPMOBILE – Holistic Urban and Peri-urban Mobility** (2019–2021) brings together municipalities, universities and other expert organisations in their efforts to develop a holistic approach to the planning, implementation, optimisation and management of integrated, sustainable mobility solutions in the Baltic Sea port cities.

The carried out activities enable major urban mobility stakeholders such as city authorities, as well as infrastructure providers and transport providers to assess and integrate innovative mobility options into their mobility management plans and policies. The developed HUPMOBILE framework allows the planning and implementation of well-functioning interfaces and links in urban- and peri-urban transport considering the different transportation flows in the local context.

Within HUPMOBILE, partner cities plan, test and implement innovative sustainable urban mobility for both people and goods (i.e. freight, cargo logistics and delivery), which are easily adaptable for follower cities. These include greener urban logistics and combinations of goods- and passenger traffic, intelligent traffic systems-based services, tools for stakeholder participation, and new tools for transportation mobility management and Mobility-as-a-Service (MaaS).

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Executive summary

The deliverable Participatory Simulation Model Development for Sustainable Urban Mobility and Logistics aims at providing a generic simulation model that interested cities can adapt. The objective of the model is to provide a solution that can support cities in developing their own multi-criteria simulation model. The simulation model is developed using the open source software SUMO. It is based on the framework development in 2.1 (Production logistics in and around cities. This document explains how interested follower cities can build their own simulation models for the production logistics operations (in and outbound transport) in their city can be developed. The underlying conceptual model also show how this can be expanded. The simulation models can be modified or changed according to the cities‘ needs.

1. Introduction

The overall aim of this WP (GoA2.3) is to develop and propose a planning approach and tools focussing on the flow of goods in urban areas. It analyses the inbound and outbound transport flows and their interaction and impact on other transport flows.

The GoA 2.3 aims to have a multi-actor based SUMP scenario model as the main output for urban and peri-urban areas. Target groups are the authorities, infrastructure providers and operators in and around the city. The main output helps to identify relevant scenarios that potentially lead to an increased capacity of passenger and freight transportation. Transportation and logistics coordination bodies such as city and port administration thus make better-informed decisions in creating more sustainable transportation flows.

A validated alternate scenario description with estimated relative merits and demerits for the pilot city are produced. This document provide a short description of the simulation model realised with Sumo which is the main output.

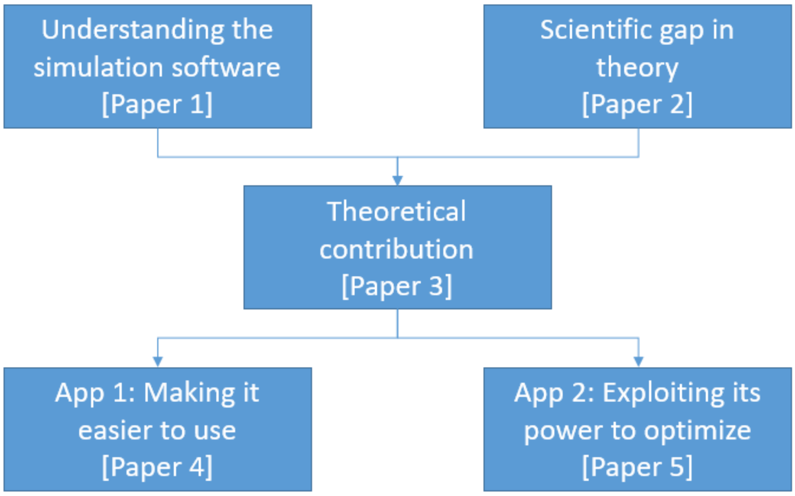
2. Research methodology

Simulation-based participatory modelling was selected and adopted as research methodology. It is a two-step process: (i) to acquaint oneself with the simulation tool, and (ii) participatory modelling. This was done in order to create simulation models in which input was provided by all stakeholders and at the same time the simulation models were validated by all stakeholders. Participatory modelling can be described as a research methodology wherein all relevant stakeholders participate in the process of decision-making and it is important to have a common mutually agreeable way of coming to consensus. We used the methodology for the development of simulation models and for creating generic guidelines for the development and transferability of the work. A brief summary of the precedence and scientific documents contributed through this project together with their titles are shown in Figure 1.

The methodology adopted has been discussed in a serious of scientific contributions [7-11]. As shown in Figure 1, we started the work in two parallel tracks, namely, understanding the simulation software and creating use cases depending upon the requirements from GoA2.2 and performing a literature review for understanding the existing theory and finding the scientific gap. In paper 1, we discussed the effects of using different types of vehicular engines on environmental sustainability and the work was presented at ISL2021 whereas in paper 2 a detailed systematic literature review was done leading to a scientific gap which is discussed in detail and is under internal review.

In the next step, the research team made a theoretical contribution and developed a framework for the use of simulation-based participatory modelling in urban logistics. This was summarized in paper

3 and in under print at Winter Simulation Conference 2021. In paper 4, we discuss and implement code to make a tool for stakeholders that help them in making changes and helping understand the outcomes of the changes made without having to know the simulation tool and how it works in depth and the contribution was presented at ISL2021. Similarly, in paper 5 the research team discussed the different options of (re-) routing heavy vehicles and studying the traditional costs and environmental sustainability aspects of the routing with the help of a Pareto optimal curve. This article is under review in Journal of Urban Mobility.



Paper 1: Urban production logistics planning considering environmental sustainability perspectives: Turku city case
Paper 2: Understanding the trends of simulation-based participatory modelling in urban and production logistics: A review
Paper 3: A Simulation-based participatory modelling framework for stakeholder involvement in urban logistics
Paper 4: A tool to facilitate participatory modelling of urban logistics
Paper 5: Minimizing vehicular noise and carbon emissions in urban areas

Figure 1: Research design for the complete project

To summarize the contributions made during the project, a multiple case study was chosen for the research done in the project. Simulations were developed for the case studies of Turku and Altona (Hamburg) wherein user specifications and requirements were collected in the first step. In the second step, simulations were created based on the requirements and studied in detail with respect to their objective functions and verified and validated. This is discussed in detail while discussing the steps to be taken for generic model building.

Empirical and semi-structured interviews were conducted to gather data and key performance indicators for the case studies to build the concept and a follow-up workshop were conducted with experts to validate the model.

3. Analysis of possible simulation software

3.1. Analysis of user needs

As the first step of looking for possible simulation software, the analysis of user needs was carried out to understand the requirements of the project. It is based on the analysis described in GoA2.2 under the lead of the city of Turku.

(i) Environmental sustainability factors

The city of Turku is looking for environmentally sustainable and cleaner ports. In pursuit of the goal, the city is in the project HUPMOBILE trying out different options including simulation creation for evaluating different environmentally sustainable options. This would include quantifying different emissions in and around port areas.

(ii) Fuel consumption and traditional cost matrix

The user needs in case of simulation for the city of Turku also required an understanding of the traditional cost matrix including fuel or power consumption. The traditional cost matrix could also include the time spent by vehicles in travelling from origin to destination or the number of vehicles completing the trips that are assigned to them.

In case of Turku, the cost was to be estimated in terms of fuel consumed and time spent with the help of simulation.

(iii) Simulation of loading/unloading of ferries

One of the requirements specified by Turku (problem owner) was simulation of in and around port region. This included simulation of different transport mediums including ferries and loading and unloading of ferries.

(iv) Simulation of parking spaces

Simulation of parking areas in and around the port region in order to calculate the parking area spaces and the number of vehicles each parking area can accommodate. The opportunity of able to distribute the vehicles in different proportions could help in decision-making in the process of vehicle distribution within parking spaces.

(v) Simulation of (re-) routing vehicles

The ability to be able to route and reroute vehicles in the region in and around the port would be useful as per the user requirements which explores the different paths and the costs attached to each path. The option to evaluate different paths help in the decision-making of which routes are favourable in terms of costs and environmental sustainability.

3.2. Derived functional requirements for the simulation tool

This section analyses the functional requirements derived from the user needs as discussed in the previous section:

(i) Possibility of map import on a city scale level

As the user requirements deals with the simulation of port areas, both in and around the port area, it becomes important that simulation software has the ability to import large scale maps. For example, the simulation software can import the map of Turku in order to create city-scale simulations.

(ii) Possibility of quantifying emissions

The ability to quantify pollutant emissions is one of the important aspects of the simulation to be created in the project as it involves the environmental sustainability point of view. The estimates of CO, CO2, HC, PMx, NOx, etc. produced allow us to specify Sustainable Urban Mobility Planning (SUMP) objectives for the stakeholders.

(iii) Possibility of quantifying time and fuel consumption

The simulation tool should be able to give us details about how much time and fuel the vehicles in aggregate needed to complete their respective trips. This allows us to represent classical objectives of efficiency and economic-viability for the stakeholders.

(iv) Possibility of simulation of different mediums of transportation

The tool should be able to model different kinds of transports to allow us to judge the effect of, e.g., commercial heavy vehicles on the pedestrian cars and the public transit system within the city.

(v) Possibility of simulation of parking areas

The scenarios we considered required modelling of parking spaces where vehicles could temporarily stop and collect during the day to allow for regulated transit during the off-peak hours. Additionally, the parking spaces too had constraints (e.g. length of parking spots, their angles, distance between two vehicles, etc.) which require consideration esp. while modelling different mediums of transportation.

(vi) Possibility to scripts

It should be possible to execute the tool in an automated fashion via a script so that it can be optimized without keeping humans in the loop. This allows for a scalable solution and trying out multiple simulation scenarios esp. for optimizing the various parameters to improve the objectives of all stakeholders.

3.3. Choice of the simulation tool

Selecting the right simulation tool is an important step, since it limits how the reality can be mirrored in the simulation models. We therefore used the criteria defined in the proposal to make a preselection of possible tools and started the discussion with the project partners at the pre-kick off meeting, which gave us input to prepare a list of software we could use was down to two choices at the first general assembly:

1. AnyLogic
2. Simulation of Urban Mobility (SUMO)

A brief comparison of their features is included here:

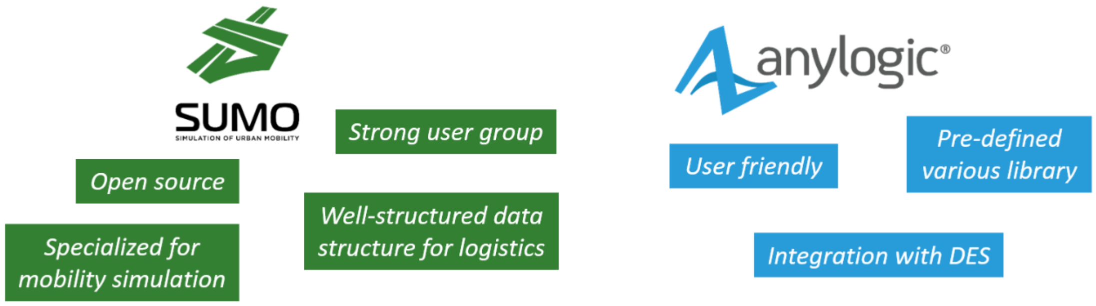


Figure 2: Comparing AnyLogic and SUMO

The costs associated with licensing of the AnyLogic tool would have limited the transferability and uptake by stakeholder cities. On the other hand, SUMO is an Open Source software being maintained by the Eclipse Foundation, which is a free and flexible environment which focus on the environmental aspects that is of specific relevance for the HUPMOBILE projct. In addition, this software allows a free export of models which can ensure that interested follower cities can build upon the findings and develop their own models, either in-house or with the help of external simulation experts.

Hence, out of these tools, we opted for SUMO.

3.3.1. Tool description

SUMO (Simulation of Urban Mobility) is an open source traffic simulation software suite available written in C++. Owing to the fact that the software is open source, it is available free for use. It is developed by DLR German Aerospace Research. SUMO allows simulation of intermodal traffic systems including motorized vehicles, public transport, cyclists and pedestrians. The software suite comes with many embedded tools for visualization, vehicle routing, network creation and import, emissions and noise calculations. Furthermore, SUMO can used together with customized models and APIs to control the simulation remotely.

According to the SUMO official documentation, the software has been used to investigate many research questions including the following:

- Evaluation of performance of traffic lights
- Investigation of vehicle route choice including developing new methods
- SUMO is widely used by the V2X community
- AI training of traffic light plans
- Simulation of the traffic effects of autonomous vehicles and platoons
- Simulation and validation of autonomous driving function in cooperation with other simulators
- Simulation of parking traffic
- Simulation of railway traffic for AI-based dispatching of vehicles
- Traffic safety and risk analysis
- Calculation of emissions (noise and pollutants)

3.3.2. Functionalities

Out of the many functionalities embedded in the software suite, following functionalities were of importance to us and were kept in mind while choosing the software from participatory modelling.

Open source: Owing to the fact that SUMO is an open source software, it is available for free of cost. As an open source software, it is being continuously developed by the user community which also provides a platform for simulation engineers to discuss the various problems that they might be working on.

Possibility to import networks, public transportation: SUMO allows importing and editing (creating) network which makes it possible for users to import city-scaled maps. For example, this property made it possible to import the maps for the city of Turku and Hamburg while creating the simulations for GoA2.2 and GoA2.4.

Importing public transportation is another important characteristic of SUMO as it helped in the simulation building for GoA2.4 and enables transferability of the tool to other cities readily.

Therefore, in general, the functionality of being able to import maps and public transportation schedule helps in transferability of results as it makes it possible to be able to follow generic steps in the simulation building.

Simulation of parking area: SUMO allows simulation of parking areas. In GoA2.2, we used this facility to be able to simulate the different parking areas around the city and make comparative scenarios.

Emission and noise calculation: The software suite has tools that allows for calculation of pollutant emissions and noise emitted by the vehicles in simulation. This also allows users to make comparisons between different types of engines (vehicle emission classes) as described by HBEFA.

Modelling of non-motorized traffic participants: The software allows modelling of non-motorized traffic participants, for example, modelling pedestrians and cyclists. It also allows simulation of zebra crossings and traffic light actuation, etc.

Modelling of traffic light system: SUMO also allows traffic light system modelling which includes both static and actuated traffic lights. This makes it possible to make a close approximation of the working of traffic lights.

Many Python helper scripts: In addition to these functionalities, SUMO software suite comes with many helper Python scripts. This facilitates rapid simulation building using the scripts.

4. Conceptual Model

Conceptual model is a schematic diagram of the real system that reduces the complexity of the system while capturing all important and relevant characteristics of the real system. While capturing the real system in a schematic diagram there are assumptions to be made on several levels:

- **System components assumptions**
- **Structural assumptions**
- **Data assumptions**

The following sections summarises the work carried out during the project and intends to give an overview. More detailed information of each part can be found in corresponding articles that we have published as a part of the HUPMOBILE dissemination activities

4.1. Generic description of the simulation model and how to make a scenario

Model Building (using SUMO)

We have discussed the theoretical generic point of view for creating the simulation. Now we discuss it from the practical viewpoint and how it is used. We used SUMO [2] as the simulation software as it is well- suited for large scaled city level traffic simulations. SUMO is also open source which makes it easier to customize the tool for a particular scenario. The software is written in C++ and has many helper scripts written in Python.

In the next section, we will discuss the generic steps to be taken in order to build a scenario in SUMO as shown in Figure 1. Since it is a multi-actor SUMP scenario building, the following steps should be taken in order to create the model:

(i) **Objective collection:** In this step, all stakeholders enumerate their objectives for developing the model. Relating to the theoretical description, this is where the objective function is decided. For example, in SUMO it is possible to look at different aspects of traffic simulation including environmental elements and the air and noise pollution produced by the traffic in terms of emissions and particulate matter. SUMO also gives an opportunity to look at different economical aspects in the form of waiting time and energy consumption. Keeping all the objectives (at times conflicting objectives in mind) the objective function is decided. Depending upon the objective function, the control variable is decided and the simulation is created.
For example, in case of SUMP scenario building the stakeholders can be city administration, municipality, citizens, private players, etc.

(ii) **Data collection:** In the second step, depending upon the objectives as set by different stakeholder data collection procedure and which data is to be collected is decided. For example, this data could be a map of the city for which the scenario modelling is to be done. It could be the traffic data or traffic light control phase data etc. This data could be the current data or the historical data available in the city databases.

Traffic Demand Modelling: In the third step, we model different traffic participants such as cyclists, pedestrians, public transport and other motorized traffic. These traffic participants are modelling using one of the traffic routers from SUMO software. Below we briefly discuss each traffic router:

Duarouter: The router imports different demand definitions, computes vehicle routes using the shortest path based on Djikstra's algorithm [3].

O/D Matrix: Origin-Destination matrix computes vehicle routes from one traffic assignment zone (TAZ) to another traffic assignment zone as discussed in the SUMO documentation [4].

Flowrouter: Flowrouter.py is a python helper script that works by solving a maximum flow problem in a given network assuming the measured flows as capacity. The input data is default aggregated over the whole file [5].

JTRRouter: JTR stands for Junction Turning Ratio which builds vehicle routes from demand definitions using junction turning percentages. The readers are directed to [6] for further reading on JTRRouter.

(iii) **Simulation:** In the next step, simulation is created using the data collected in the data collection phase together with the traffic input demand. The simulation is then run with different values for control variables with respect to the given objective functions. Constraints or boundary conditions are also applied to the simulation while it is created.

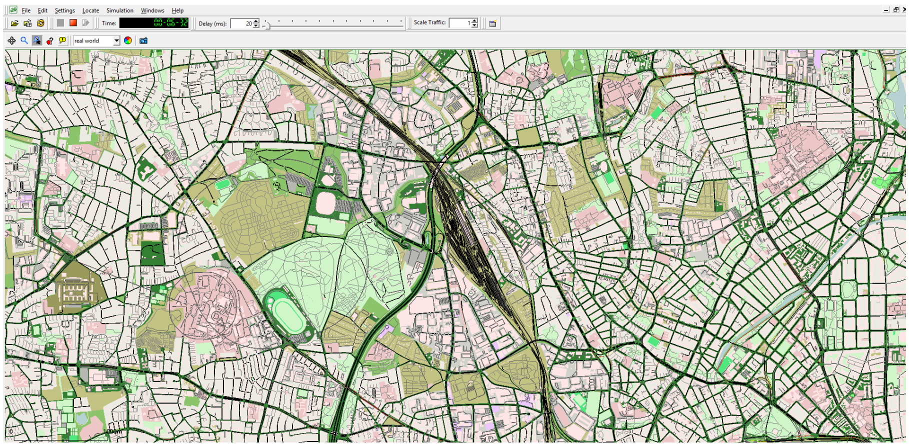


Figure 3: An example of a SUMO simulation

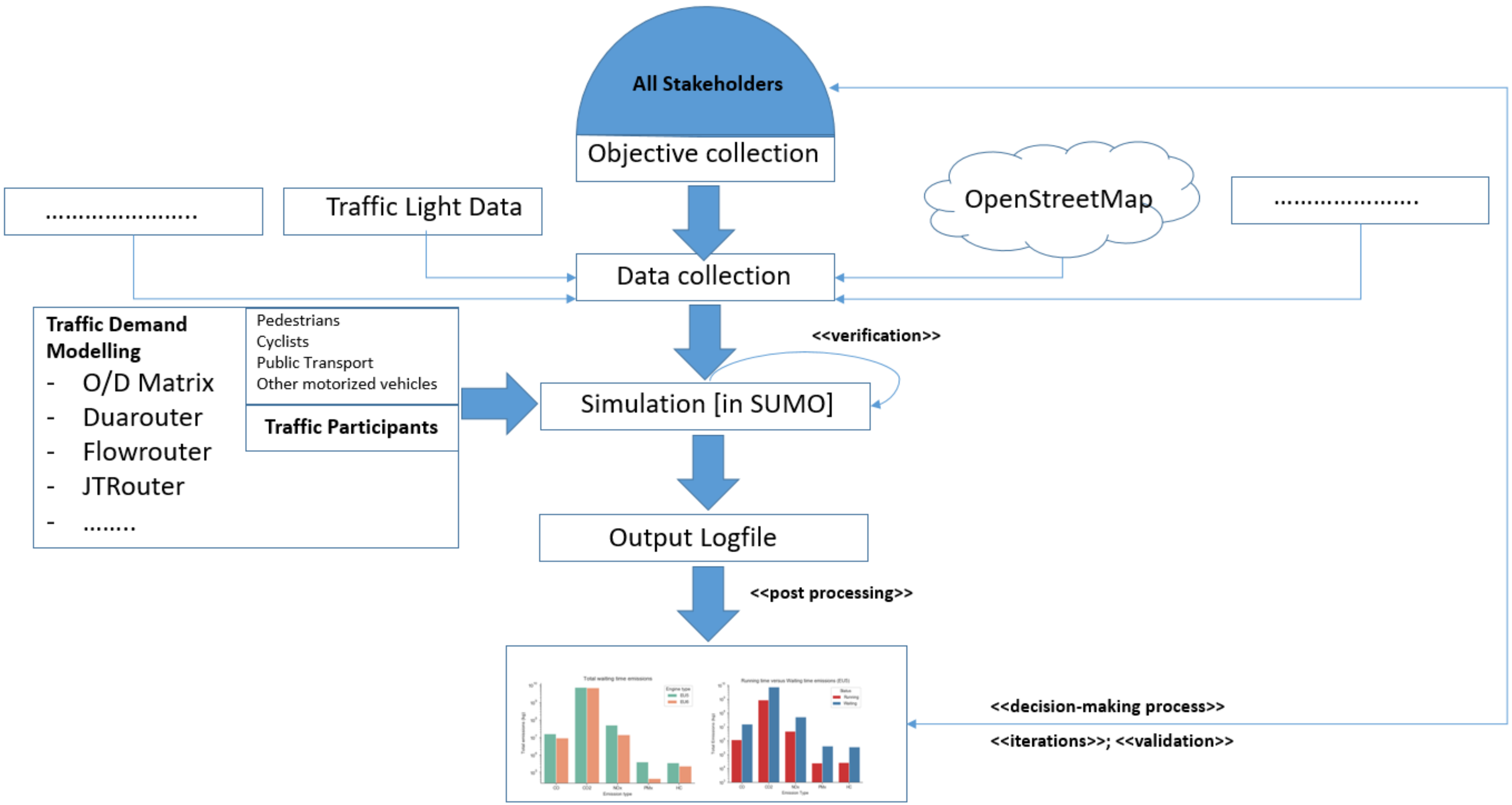


Figure 4: Description of generic model development in SUMO

(iv) **Output Logfile:** Each simulation run results in simulation output that is in the form of a logfile in excel wherein different results are logged with respect to time as shown in Figure 5.

There are different variables reported in the logfile with respect to time step of one second. These variables vary from different time calculations like time taken for a vehicle to complete a trip or the time when a vehicle was not moving, etc. to different environment sustainability parameters, like, measuring CO2, CO, PMx, NOx, HC produced etc. to variables considering different measurements from the vehicles, like speed, acceleration, deceleration, etc.

(v) **Results:** In the last step, the output logfile is processed to gain insights from the dump output data created as shown in Figure 1. These insights help stakeholders and decision-makers to reach to a conclusion and further iterations are based on these insights and results.

4.2. Tool description for changing scenarios

This section discusses the design approach adopted for the research work presented here. First, we discuss the approach to build the tool, second, we will discuss the technicalities of how to build such a tool and lastly we will discuss how to present the results.

In the first step, a software simulator suitable for simulation of the scenarios presented is chosen. In our case, SUMO (Simulation of Urban Mobility) was chosen as the preferred software since it allows for city-wide simulations which was required in the case study.

SUMO is an open source, highly portable, continuous and microscopic software, which is aimed at simulation of large networks. Readers interested in SUMO are referred to https://www.eclipse.org/sumo/.

For the case study, it is of importance that with the help of the simulations we could quantify the waiting time for vehicles, fuel consumed together, and environmental sustainability aspects. All these features are covered in SUMO simulations. Thus, it further strengthened the reasons why SUMO should be apt for making simulation-based participatory modelling.

Next, the control variables of the simulation is chosen by the stakeholders resulting in the understanding of which parameters can we modify while simulating the scenarios. For example, control variables in this case study can be different distribution of heavy vehicles coming from all directions. Domain experts together with the stakeholders introduce the constraints in the simulation, e.g., on certain roads within the city trucks are not allowed, etc.

During the discussions with stakeholders and problem-owners, we came to understand that the stakeholders lacked the technical know-how to operate simulation-software directly, hence, this tool was proposed in order to help the stakeholders in the process.

One of our objectives while developing the tool was that it will help with uptake of our approach with other cities and stakeholders as well.

Building the tool:

In the next step, the tool is built keeping in mind the requirements as discussed in the previous section. A GUI python program was written that takes as input the SUMO configuration files and outputs the result as shown in Figure 2. The SUMO simulation, in turn, takes OpenStreetMap and Origin/Destination matrix as input.

Python is selected as the language to programme the GUI and we used tkinter (**https://docs.python.org/3/library/tkinter.html**) to create the user interface. The GUI on press of button calls SUMO which together with the template input file and the input given through GUI creates the concrete input files. The concrete input files are then passed to SUMO as input. SUMO runs the simulation based on this input and produces output in the form of XML files. These XML files are then processed to produce the output. In the next step, we discuss how output can be presented.

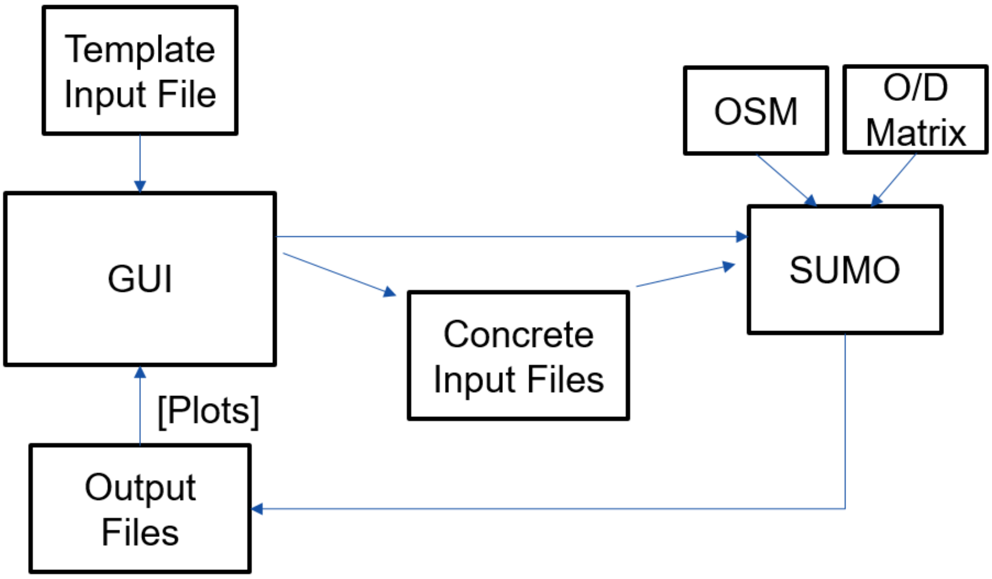


Figure 5: Figure shows schematic diagram of the tool and its interaction with SUMO

Results presentation:

Based on the user requirements, the objective functions are shown as the output from simulations. Results presentation primarily depend on this objective function and is decided by the stakeholders involved in process. For example, environmental sustainability aspects are the objective function for this case study and we visualize that objective function as shown in Figure 3. As shown in Figure 3, the results are presented in the form of bar graphs. This helps in different scenario comparisons and their visualization in an apt way.

This section provides a brief description of the case study for which the tool is made.

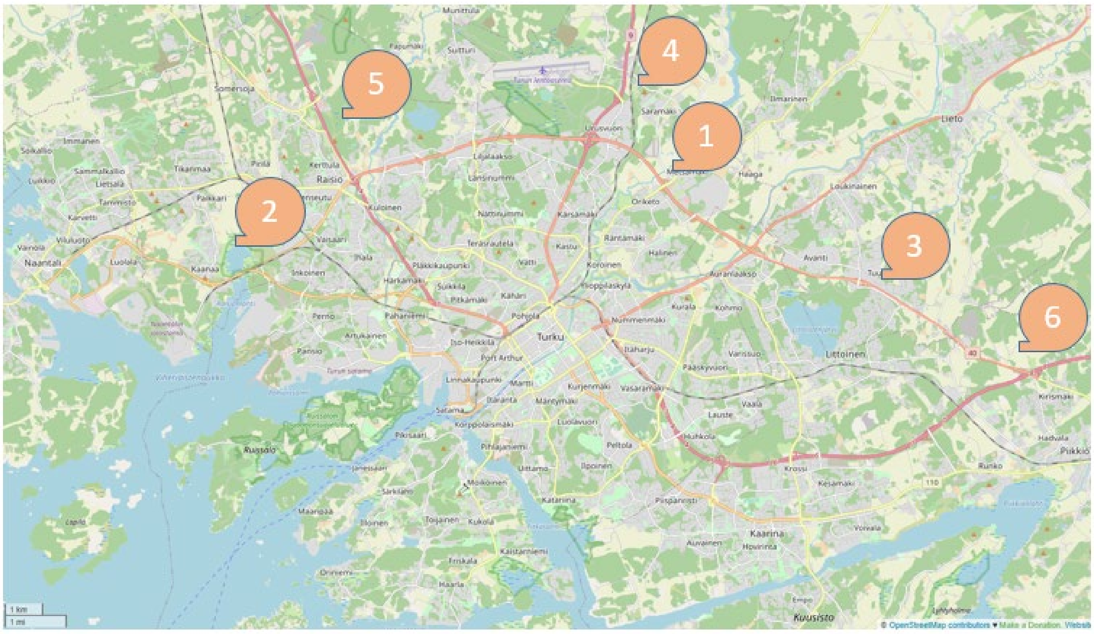


Figure 6: Figure shows six different parking lots where heavy vehicles need to wait before entering the city.

In this case, a city is investigating how heavy commercial vehicles travelling to the destination from different directions can be coordinated. There are six different parking lots where the heavy commercial vehicles coming to the port from outside the city are required to wait and they enter the city when allowed by the city authorities to travel to the port as shown in Figure 1. There are different performance indicators based on which the decision has to be made. Following are the key performance indicators in decision-making:

- Parking spaces available in each parking area
- Time required to travel to the port
- Waiting time for the trucks stuck in traffic jam
- Fuel consumed as the traditional cost metrics
- Environmental emissions emitted by vehicles

Different stakeholders, and research partners meet to discuss through simulations the different scenarios and the advantages and disadvantages of each scenario by using the numerical results from simulations.

In response to these time-consuming iterations, a tool is proposed wherein the iterations are automated with the help of a Graphical User Interface (GUI). A prototype of this GUI tool is shown in Figure 3.

This authors would want to investigate the following research questions based on the usability of the tool:

- Does the tool increase the pace of discussion and thus save time?
- Is the tool able to improve the satisfaction of the participant stakeholders?

The tool was developed and the above-mentioned are being tested first internally and then presented to stakeholders (Turku case study GoA2.2).

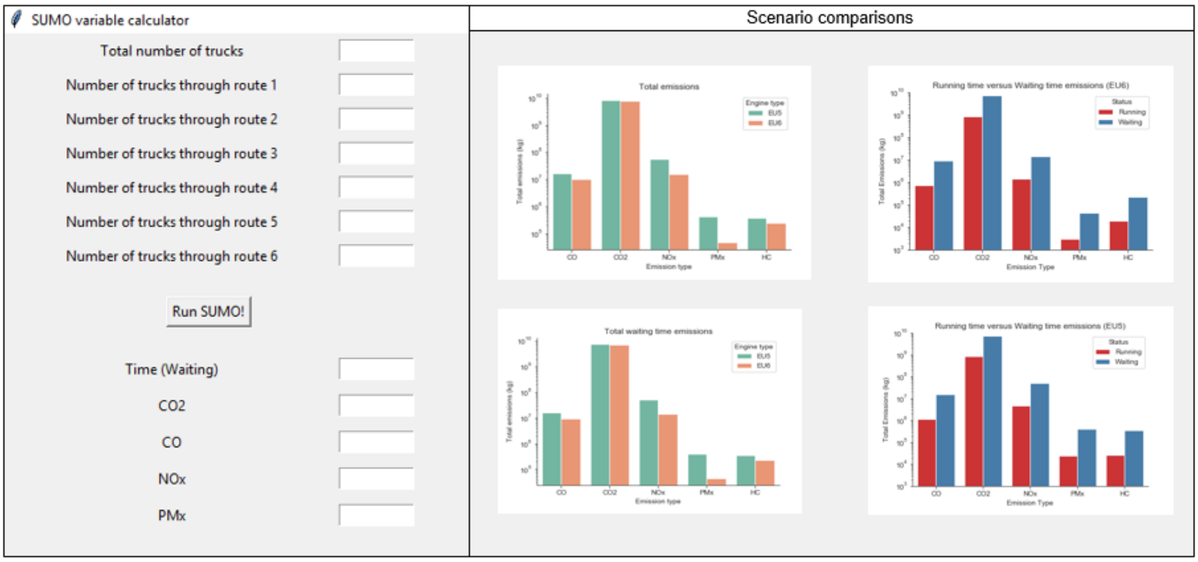
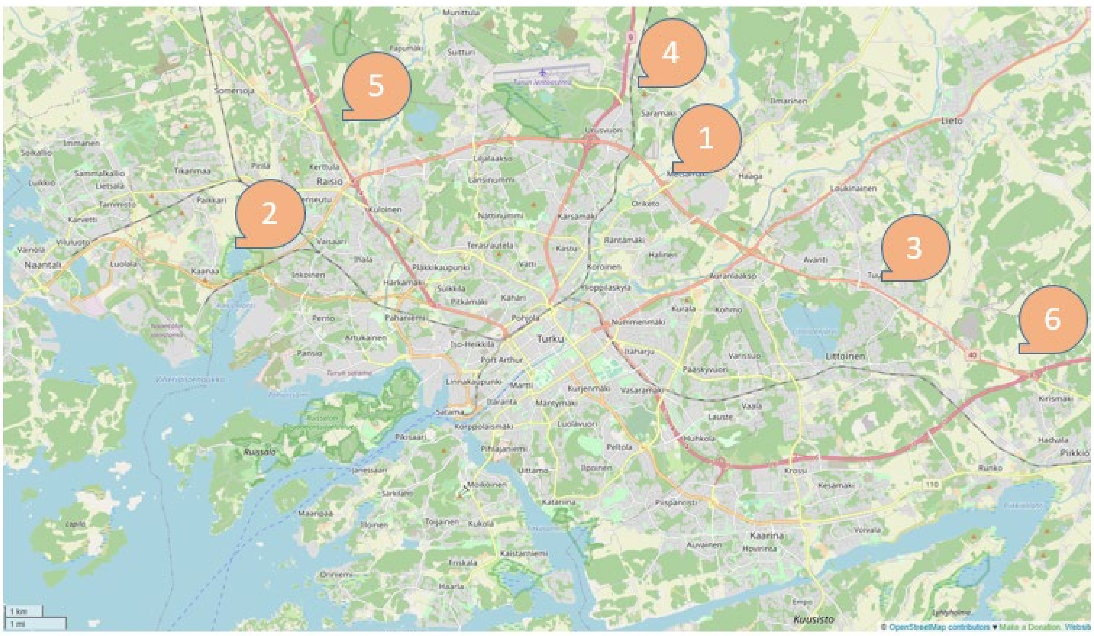


Figure 7: Figure shows interface of the tool (based on SUMO)

4.3. Example of developing a scenario using the model- TURKU case (very short)

Since we followed as per the project requirements the participatory modelling approach, it was of utmost importance that views of all stakeholders were taken into consideration while making the simulation options and in the process of decision-making. So while developing the simulation models it was important to keep in mind that all stakeholders, in case of GoA2.2, both stakeholders: the city of Turku and port of Turku representatives were actively involved in the process of decision-making.



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5. Verification of conceptual and simulation model

Banks, J. et al. [12], in their book on simulation define verification as an act of building a simulation model correctly. Verification is the comparison of the conceptual model to the computer representation that implements the conception. It further checks if the input parameters and logical structure of the model are correctly represented.

We verified our generic model building approach in the following manner:

5.1. Comparing against the 2.1 framework

Within the task 2.1 we developed a framework "Developing a holistic decision support framework: From production logistics to sustainable freight transport in an urban environment" (https://doi.org/10.1016/j.trip.2021.100496). The main purpose of that framework is to lay the foundation for a multi-criteria, multi-stakeholder and multi-level decision support. The framework itself is based on IDEF 0 methodology. The presented framework is derived of a combination of a literature review and analysis of existing research project results before. It supports the collaborative decision making at different level. The framework factors are identified, and possible relationships across the various layers are indicated. The field of application is the area near urban manufacturing sites and specifically addressing all actors that share on regulate infrastructure relevant to last mile inbound logistics. This can be seen as the full conceptual model. The verification of the simulation followed by carefully check the reduction of the conceptual model with its corresponding simulation models. The verification shows that the simulation corresponds to a simplification of the conceptual model. While the conceptual model can be both continuous as well as used for discrete time or discrete event, the simulation model is limited by the software which is based on a time discrete simulation. However, the simulation model allows set the time interval sufficiently small. Another limitation is the lack of sufficient data (for each of the input variables) to be imported. This requires simplification which are only allowed by defining boundaries for the simulation. Currently a boundary besides the system restriction and input variables are also by the transport means ferries, different types of trucks and lorries, busses, cars, cycles and pedestrians. Other transport means will be verified in D5.3.

5.2. Case study done with a Swedish automotive manufacturer

In order to verify our generic model building approach to develop detailed case studies, we also worked with a Swedish automotive manufacturer. We build the models together with the representatives of the automotive manufacturer and found out that the approach was successful; we were able to perform and evaluate simulations for test models.

These models belonged to different assembly lines of the factory and using the steps from the generic model we could successfully build the simulation models, verify them with the help of the simulation engineers from the company and finally validated the models against the real life scenarios and operation times from the factory.

5.3. Verification through simulation experts

During the course of the project, Master level students were assigned a task in the course "**Modelling, Simulation, and Optimization of Production Logistics" (ML2302)** to use the tools to develop models for other companies and cities. These simulation models used the generic methodology developed by researchers in this project and was further verified by other teachers in the course who are not directly involved in HUPMOBILE but are simulation experts at KTH. This provided evidence of both the ease of uptake of the tool as well as transferability of the approach.

6. Validation of simulation model

According to J. Banks et al., validation is concerned with building the correct model. It attempts to confirm that the simulation model built is a correct representation of the real world. This is achieved through continuous iterations of the simulation model by comparing it to the real world and making changes in the simulation model as new insights and knowledge is gained.

6.1. Expert validation (Simulation expert)

In the first validation step, the model was shown to simulation experts from a company. With the help of these simulation experts, the models were iterated depending upon their feedback and comments and was validated by them. In this step, we concentrated only on the aspect of simulation building and it is corresponds to the right model. Pär Mårtensson and Bhargav Mahesh (from Scania, Sweden) were the simulation experts consulted in the matter.

6.2. Expert validation (Field expert)

In the next validation step, the simulation model was shared with the end users to validate if it fulfils the needs and requirements as mentioned by end users in the objective of model building. This validation was done by the problem owner, that is, the city of Turku (Juha Jokela) and port of Turku (Markku Alahäme). From these two field experts we validated our simulation models that they perform the intended purpose for which they were made.

7. Limitations

7.1. Possibility of running simulation models on problem owners' computers

We were unable to deploy the tools on the computers of the stakeholders due to restrictions put in place by the IT department from the stakeholder side. Attempting to work around these restrictions led to increase in the lead time between iterations. In future, we should include the IT restrictions as part of the user-requirements we collect.

7.2. Travel restrictions imposed due to global pandemic

Due to COVID-19 restrictions, we were unable to meet and hold workshops with the stakeholders. We were unable to see the roads, ports, and parking areas for which we were developing the simulations models. The lack of in-person workshops and interviews hindered the transfer of the solutions to the stakeholder experts. We are continuously adapting to these restrictions.

7.3. Data fidelity/ granularity

Lastly, fine-grained data to develop the simulation models was not easily available. Instead, we had to develop models based on coarse grained data (e.g., daily-average data or vehicle-kilometre instead of hourly or per vehicle data). Though we had data about the intersection traffic and vehicle types for Turku, it was still missing details (e.g., turning ratios) which would have allowed us to fully reconstruct the vehicle trips. If higher fidelity data was available, we would have been able to capture the nuances of the scenario much better.

8. Conclusion and Outlook

In the GoA 2.3, a generic methodology for simulation-based participatory modelling using SUMP objectives was developed and further used in GoA 2.2 and GoA 2.4 to build simulation models for the port of Turku and city of Hamburg. The same simulation models will be used for GoA5.3, in which they will be expanded for different other urban logistics configurations, also taking the challenges faced in GoA2.4 into account.

We were able to develop models corresponding to GoA2.2 and 2.4, verify them, and validate them with experts. We were also able to reduce the delay between iterations as we facilitated the discussions and empowered the stakeholders with the tools we developed during the project.

However, we also had some difficulties which could be addressed for the ensuing projects.

Though support from the open-source community was available, learning the SUMO tool was still an uphill task. We are building expertise in that tool by offering SUMO lab sessions and making it an integral part of courses in the university. We have included SUMO lab sessions in the "**Modelling, Simulation, and Optimization of Production Logistics" (ML2302)** offered at Master level studies at KTH.

9. Own publication contributed to this work

There are scientific contributions made in the field during the course of the project. Below the reader would find a short descriptions of the scientific contributions made.

8.1 Urban production logistics planning considering environmental sustainability perspectives: Turku city case

The EU policies in the Baltic Sea Region (BSR) focusses on sustainable energy development through integration of greener ports [1,2]. In line with the EU goals for BSR, the purpose of this paper is to present a generic model building approach to understand and quantify the aspects of environmental sustainability in terms of vehicular emissions in the port regions. One pertinent way of realizing the quantification of pollutant emissions is based on the engine models of vehicles. For this, simulation was chosen as the mode of study as we described the characteristics of both as-is and to-be models. According to existing literature, SUMO software is the best fit as the modelling tool when it comes to modelling environmental sustainability [3].

8.2 A tool to facilitate participatory modelling of urban logistics

Optimizing urban logistics is a complex multi-stakeholder and multi-criteria decision problem. This paper presents a tool made for a case study wherein a city is investigating different options for heavy commercial vehicles to traverse the city and calculating how much pollution they produce. In the process, participatory modelling is adopted as the method for research and development of the case. The participatory modelling approach facilitate production of data by individuals and ensure that a participant's input is processed in a transparent manner [4]. Communication, hence, becomes a key aspect of participatory modelling [5]. Communication can be made more concrete if it is based on quantitative data. Also, research has shown that participatory modelling based on a relevant tool engages stakeholders more as compared to stakeholders with no tool used in a discussion [6]. We, in this paper, discuss a case study of participatory modelling in which we make the communication better and aid in the process of decision-making by providing stakeholders with a prototype of a tool based on the SUMO software.

8.3 Understanding the trends of simulation-based participatory modelling in urban and production logistics: A review

The use of participatory modelling has been continuously increasing in recent years due to the increase in the number of stakeholders participating in the process of decision-making in all fields including logistics. With a view of achieving better understanding of the subject, this article systematically reviews the advances made in participatory modelling in the field of urban and production logistics in the last decade. It further reports the findings transparently following categorization based on (i) the purpose of participatory modelling in the domain, and (ii) depending on the purpose how data is collected, processed and outcomes are presented. The review resulted in 97 articles which were analysed and categorized based on the above two questions formulated based on the literature surveyed. The review revealed that apart from the three existing categories of purposes, namely, reflexive, normative and communicative there is an emerging fourth category that was analytical in nature and 14 put of 97 articles analysed belonged to this category. The research team decided to call this analytical field empirical modelling which is primarily based on mathematical modelling and use of computational methods. During the analysis for the second research question, we discovered that though the conventional ways of data collection and processing, like interviews and workshops still had a strong presence there is a rise in electronic data crowdsourcing and data processing using computational methods.

8.4 Minimizing vehicular noise and carbon emissions in urban areas

Faced with the demands of sustainability and reducing carbon emissions together with the existing requirements of minimizing costs incurred, the field of transport is witnessing a paradigm shift. Stakeholders pay increased attention to streamlining their operations with respect to the abovementioned criteria. So far, the effect of vehicular flow on the environment was seen as a by-product of overall optimization of costs incurred. However, now, with the world moving towards sustainability and carbon neutrality, the effects of vehicular flow on the environment have come to the forefront of problem-solving together with cost optimization. Simulation-based optimization has been widely used in controlling traffic lights and, hence, the controlling of the vehicular flow through a town, but not much effort has been made in the area of minimizing carbon emissions in a traffic flow and the literature on it remains sparse. This article integrates operational and environmental boundaries by proposing a specific approach combining simulation and a multi-objective evolutionary algorithm to simultaneously optimize vehicular noise, emissions and traditional costs metrics. The optimization procedure brings forth a Pareto optimal front highlighting the trade-offs involved in the decision and provides all stakeholders, including policy-makers, town administration and traffic management with a set of alternatives to choose from.

8.5 A Simulation-based participatory modelling framework for stakeholder involvement in urban logistics

The popularity of both computer-based simulations and participatory modelling individually have supported design and research of many case studies. However, not much work has been done in the collaborative area wherein both the decision-making tools are used together for problem solving in the domain of urban logistics and the peer-reviewed literature on it remains sparse. This paper suggests a combination of the two fields for developing research in the area of development of urban logistics intensifying sustainability. In response to the requirements of simulation-based participatory modelling, we present a generic framework for developing these models. The framework facilitates dialogue among stakeholders with the help of a participation scheme which defines the level of participation of each stakeholder. Though the framework is presented in context of simulation-based participatory modelling, it can be easily extended to other modelling techniques.

10. References

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